



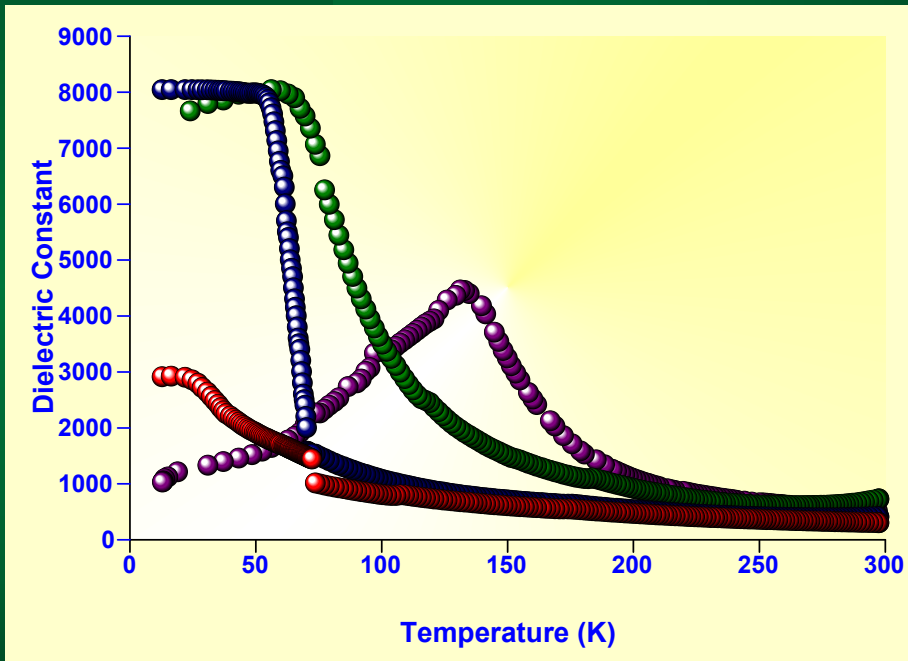
# Cryogenic Deformable Mirror Technology Development



# Cryogenic Materials Development



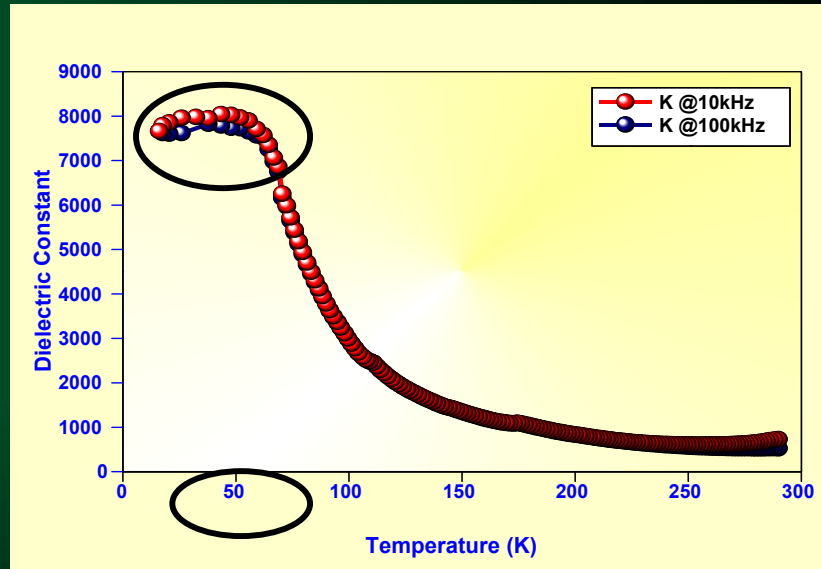
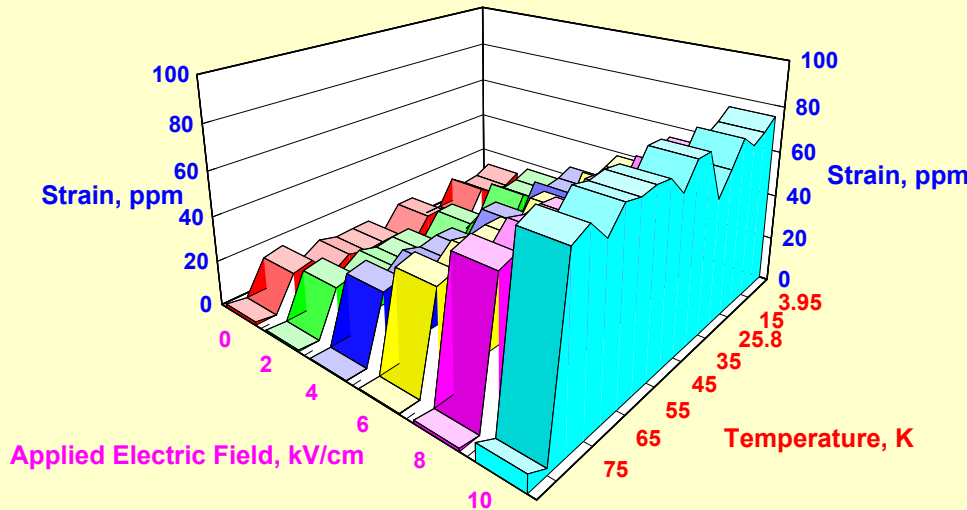
# Operating Temp Range Shifted by Doping



- ◆ Dopant Concentration Shifts Transition Range to Higher Temperatures
- ◆ Dopants Enable Broad Phase Transition



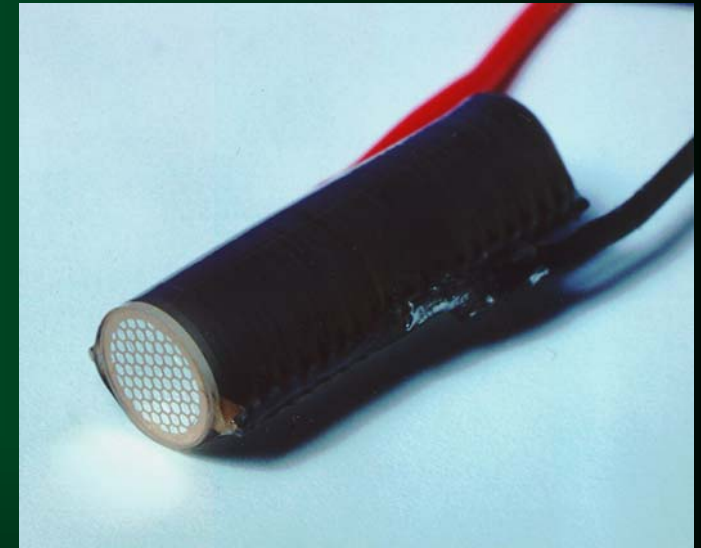
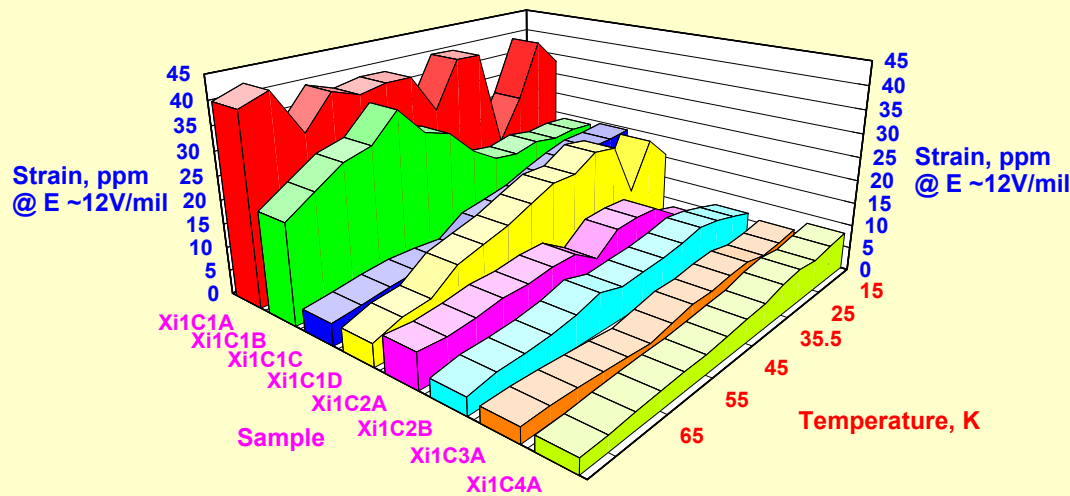
# Stroke is Proportional to Dielectric Constant Enables Fast Track Material Tailoring



◆ Near Linear Dielectric constant and Strain observed between 25-65 K

# Low Field Tests Demonstrate Actuator Stroke

## Broad Temperature Response Enhances System Control



- 20 Ceramic Compositions Tested
- Capacitance Measured 25 - 80K
- Stroke Measured From 25 - 80K
- Test Stacks Formed by Epoxy Bonding
- Structural Epoxy Holds Layers Together
- Mesh Electrodes

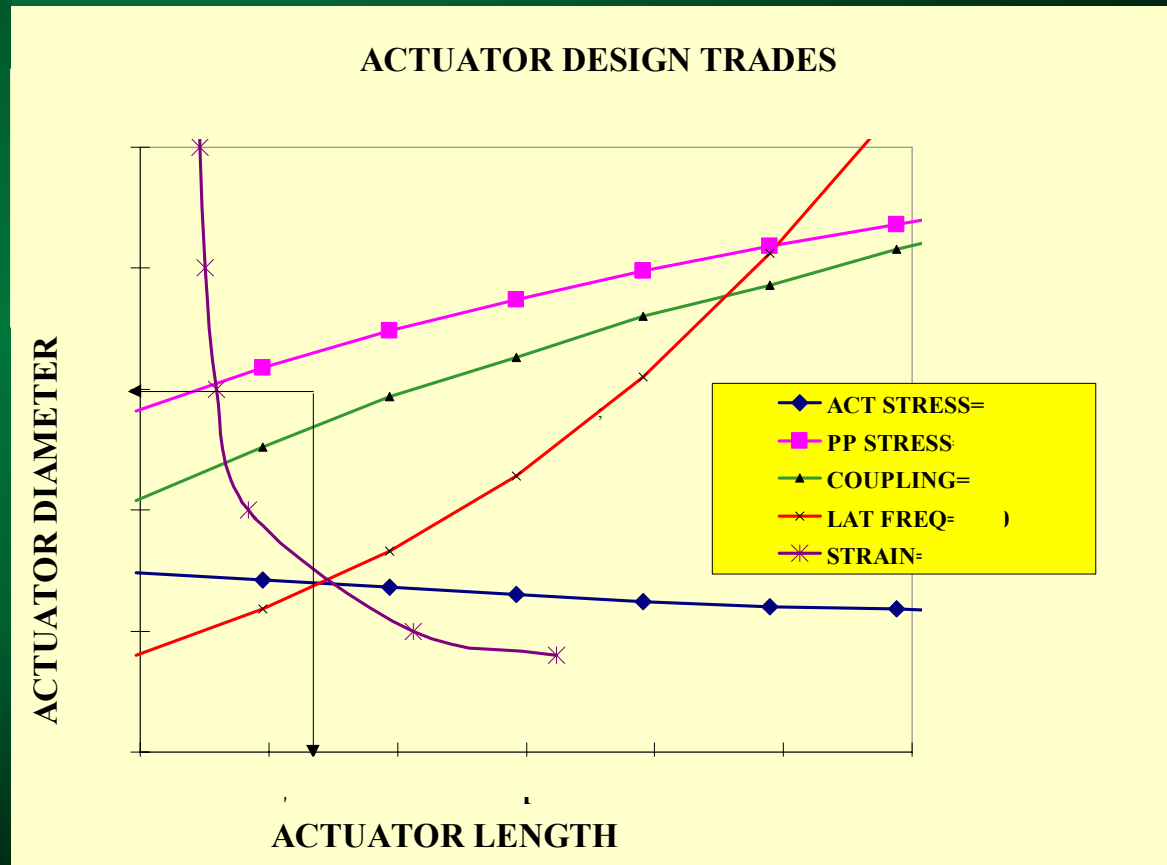


# Cryogenic Mirror Design



# Actuator Design Specific to DM Application

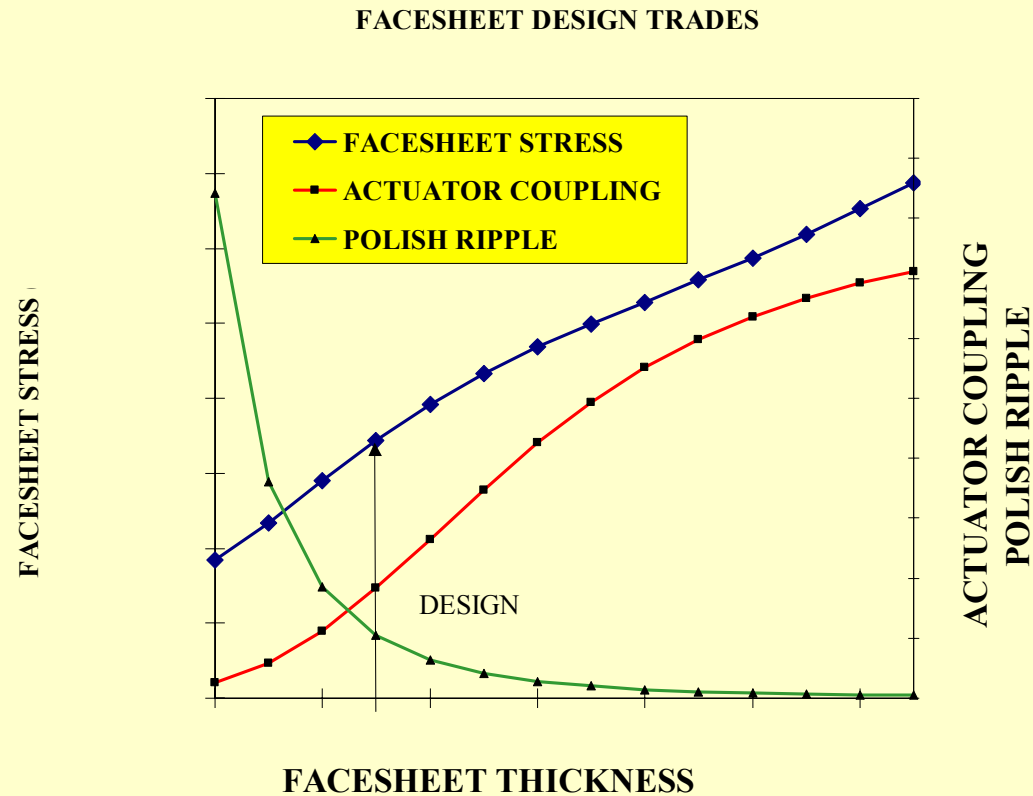
## Induced Stress, Polish Ripple, & Influence Function





# Facesheet Design Matched to Actuators

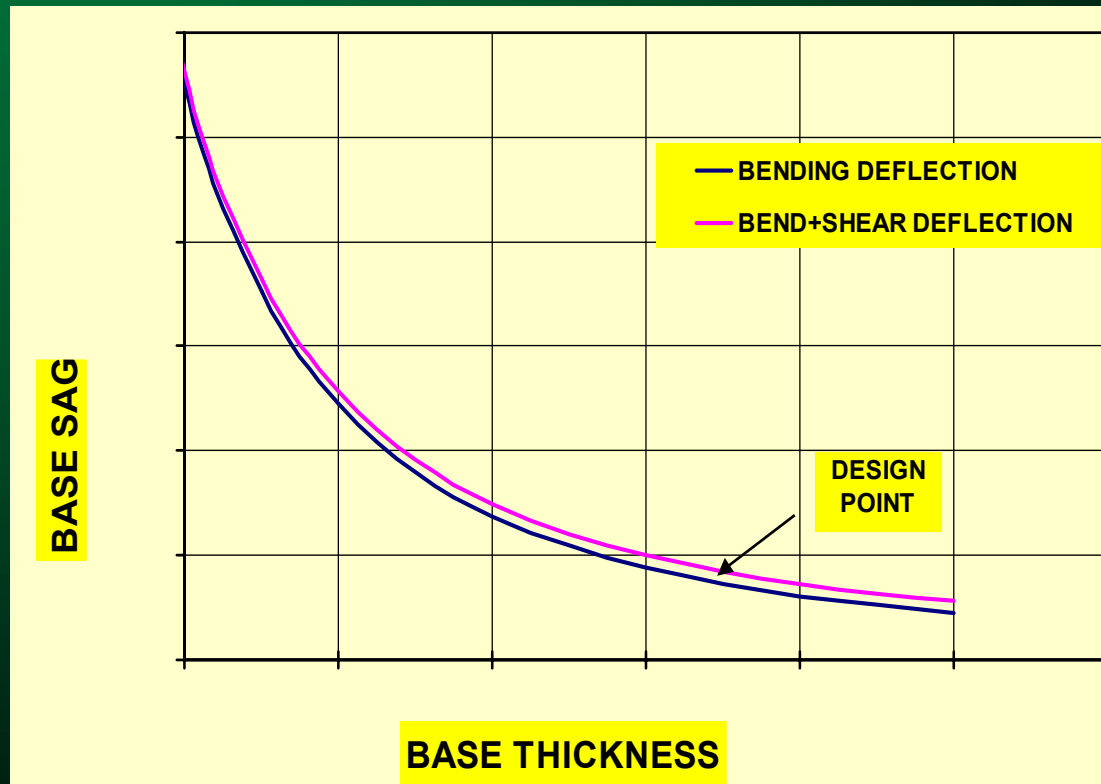
## Induced Stress, Polish Ripple, & Influence Function





# Bezel Design Matched to Mirror Structure

## Thermal Match, Structural Response & Gravity Sag





# Cryogenic Mirror Fabrication & Test

# Phase II Cryogenic DM Pathfinders

*Scaled to 349-Channels Composed of C&B Actuators*



**Xinetics Inc.**

Precision Motion Under Intelligent Control

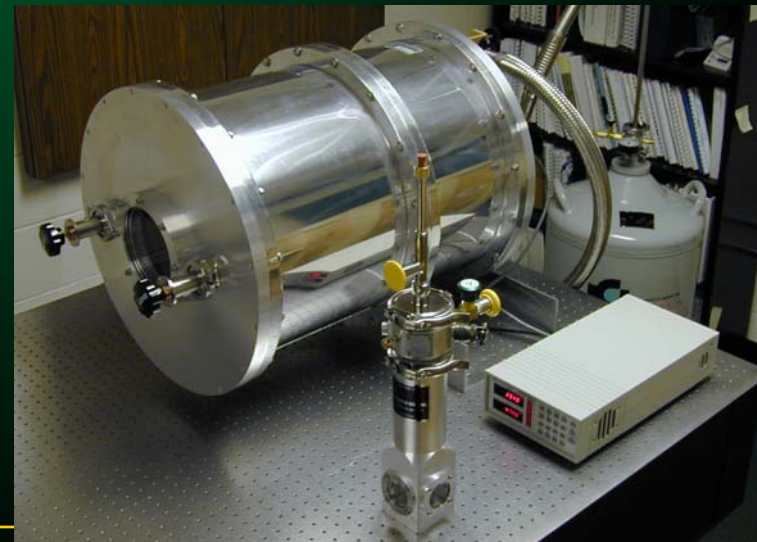
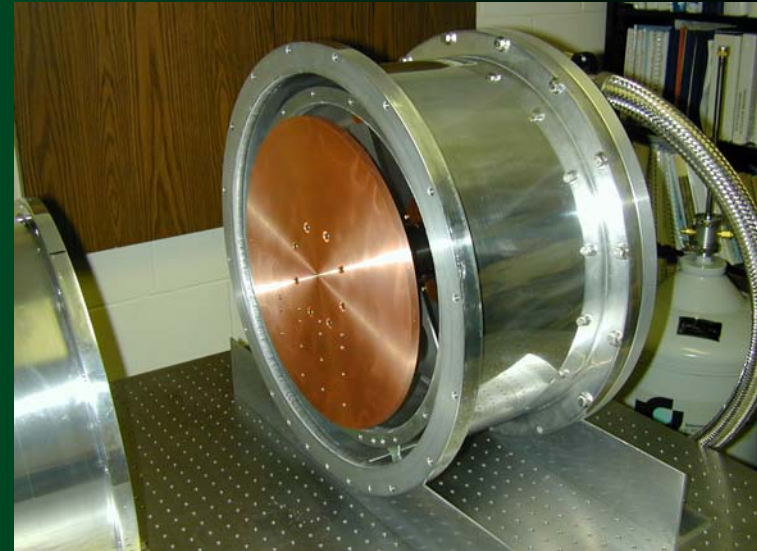
Mark A. Ealey, et.al.



# Xinetics Cryogenic Testing Facility

## *Cryogenic chamber for testing optics up to 15"*

- ◆ Max Sample size 15" dia by 10" deep.
- ◆ 6" dia quartz windows provide  $\sim\lambda/6$  PV quality.
- ◆ Continuous flow cryostat
- ◆ Cooling with either LHe or LN2
- ◆ Temperature range 4 - 475K
- ◆ Temperature control  $< \pm 0.1K$
- ◆ Cool down from RT to 10K  $\sim 6$  hrs
- ◆ Mounts horizontal on optical bench for testing with Zygo interferometer
- ◆ 19 pin electrical feed through expandable to  $\sim 2000$
- ◆ Large diameter cold finger designed to support heavy mirror assembly.
- ◆ Mechanical snubbers designed to damp vibrations
- ◆ Optical shutter minimizes gradients in windows
- ◆ Electrical interface compatible with ST-100
- ◆ Vacuum fittings compatible with ST-100



**Xinetics Inc.**

Precision Motion Under Intelligent Control

Mark A. Ealey, et.al.

ξ

## Φ2 37-ch Cryogenic C&B Actuator DM

*Test: Successfully cycled twice to 35K*

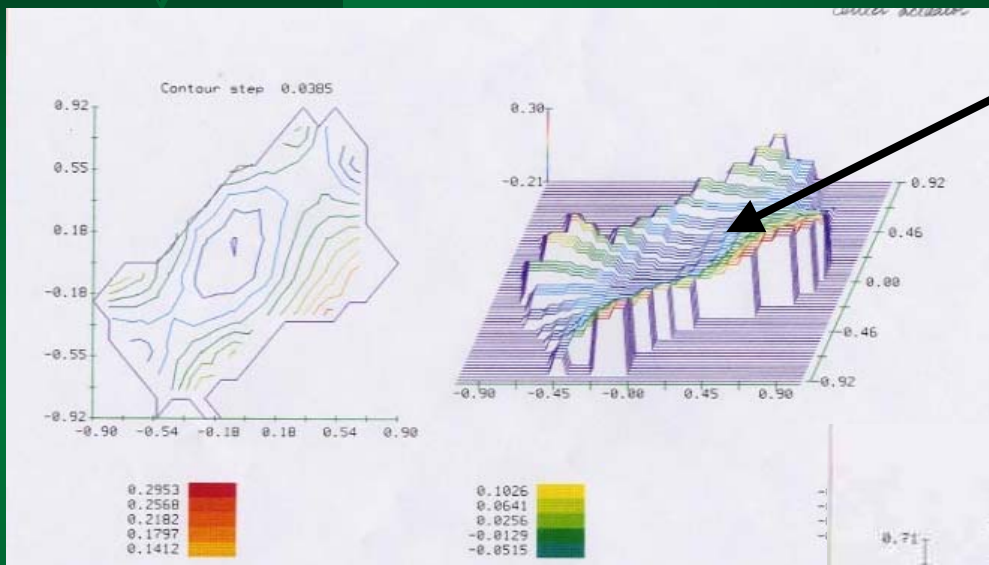


Mounted in Cryogenic Chamber



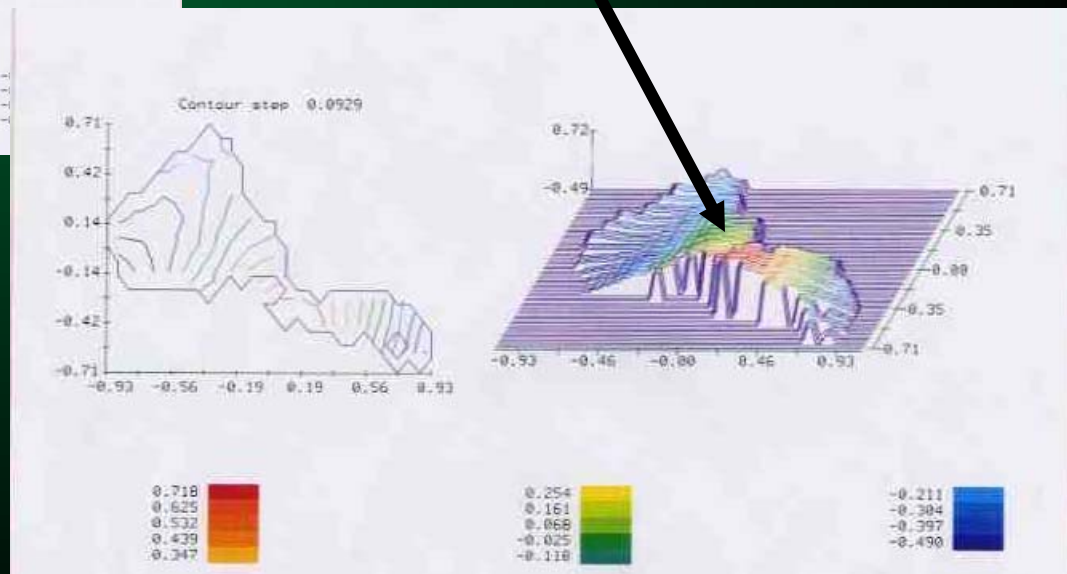
# C&B Actuators Pushed on the Facesheet

*$\Phi 3$  Test @ 35K and 250V (14V/mil, 5.5kV/cm)*



Center actuator unpowered

Center actuator pushing on facesheet @ 250V



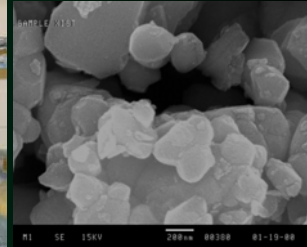


$\phi 3$  Cofired Actuator Development

# Stages of Cofired Actuator Development

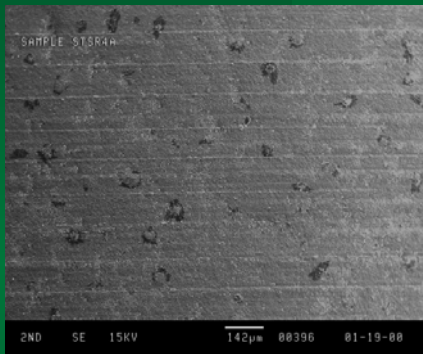


## Powder Processing



Powder Processing

## Electrical Connections



Electrical Connections

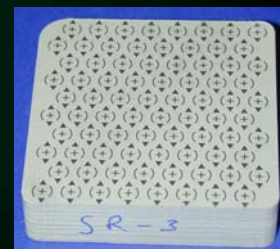
## Tape Casting & Laminating



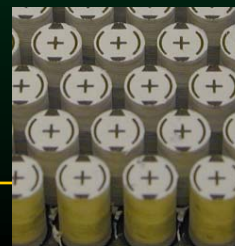
Tape Casting & Laminating

Screen Printing & Coring

## Screen Printing



## Coring



Thermal Cycling



## Binder Burnout Sintering



**Xinğtics Inc.**

Precision Motion Under Intelligent Control

Mark A. Ealey, et.al.  
**Proprietary**

§

## Approximately 400 Cofired Actuators \*Tailored to 30 to 65K Response*



Xinetics Inc.

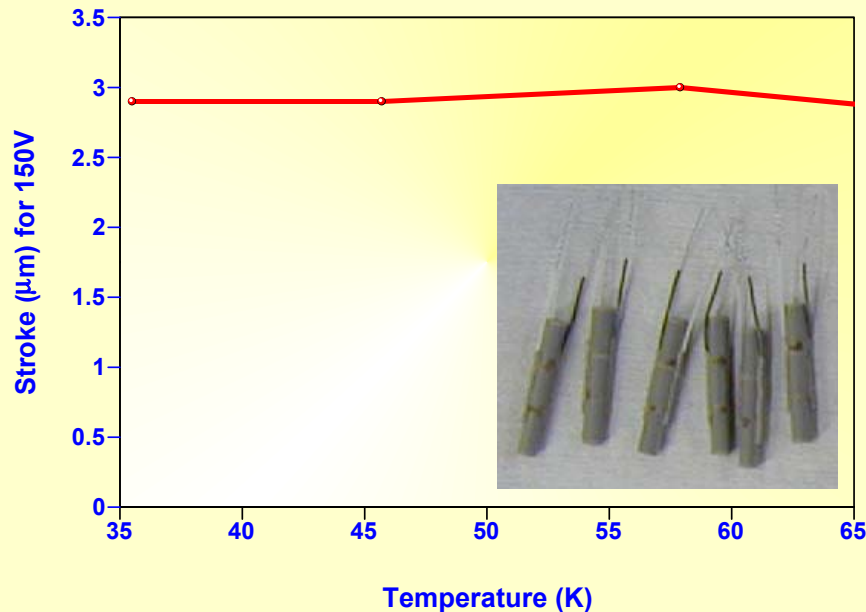
Precision Motion Under Intelligent Control

Mark A. Ealey, et.al.



# NGST Cryogenic Actuator Evolution

## *Φ3 Development: Cofired Actuator Response*

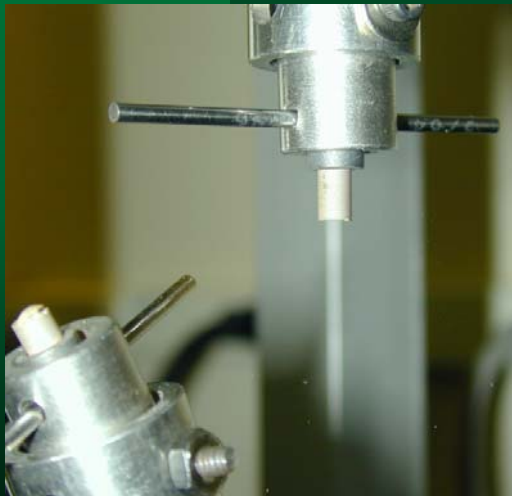


- Xinetics cryo-cofired actuators were electrically cycled between 35 & 65 K over 10 times.
  - Strain response very linear from 35 to 65K.
  - Broad temperature response.
  - Response of cryogenic cofired actuator for Phase III Cryo- 349-ch DM.
- ✓ Therefore, the cofired actuators for the cofired 349-ch cryogenic DM to be built under Task 2 in Phase III program will stroke ~3 μm at 150V.



# Tensile Strength is critical to DM design

*Φ3 Exceeds 4000 psi at 35K*



- ◆ Cryogenic actuators must push/pull on a face sheet.
- ◆ Design requires that actuators exhibit  $> 2000$  psi of tensile strength, which has been measured at 35 and 300 K.
- ◆ Measure of electrode/ceramic interface, breakage through several layers has been observed.
- ◆ SEM microstructural analysis confirms good adhesion between ST and Pt.

**Xinξtics Inc.**

Precision Motion Under Intelligent Control

Mark A. Ealey, et.al.

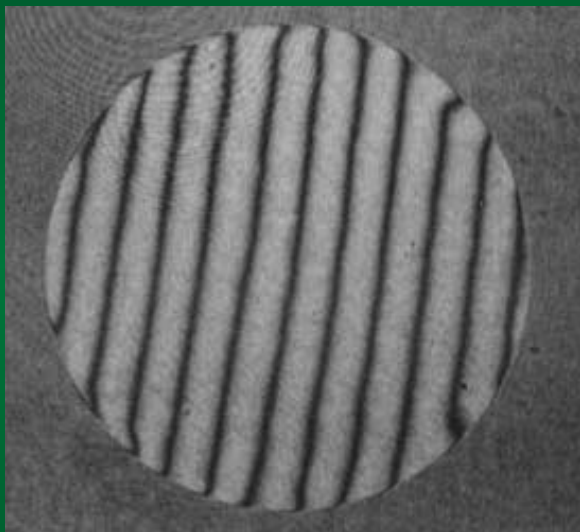


$\phi^3$  Cofixed Deformable Mirror



# NGST Cryogenic DM Demonstrator

## *Φ3: Cryogenic 349-ch Discrete Actuator DM*



*After Polishing Stats*

- ❖  $\lambda/5$  p-v
- ❖  $\leq 20$  Å rms
- ❖  $\leq 60/40$



**Xinetics Inc.**

Precision Motion Under Intelligent Control

Mark A. Ealey, et.al.



## 349-ch XiMux Electronics Driver System



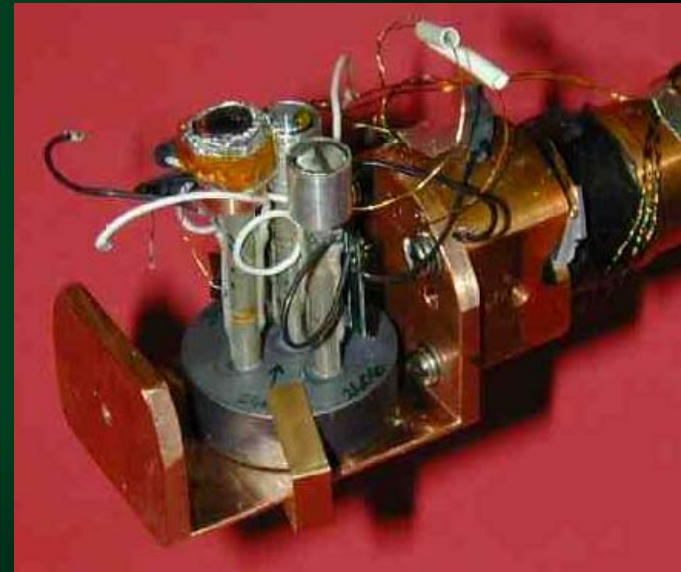
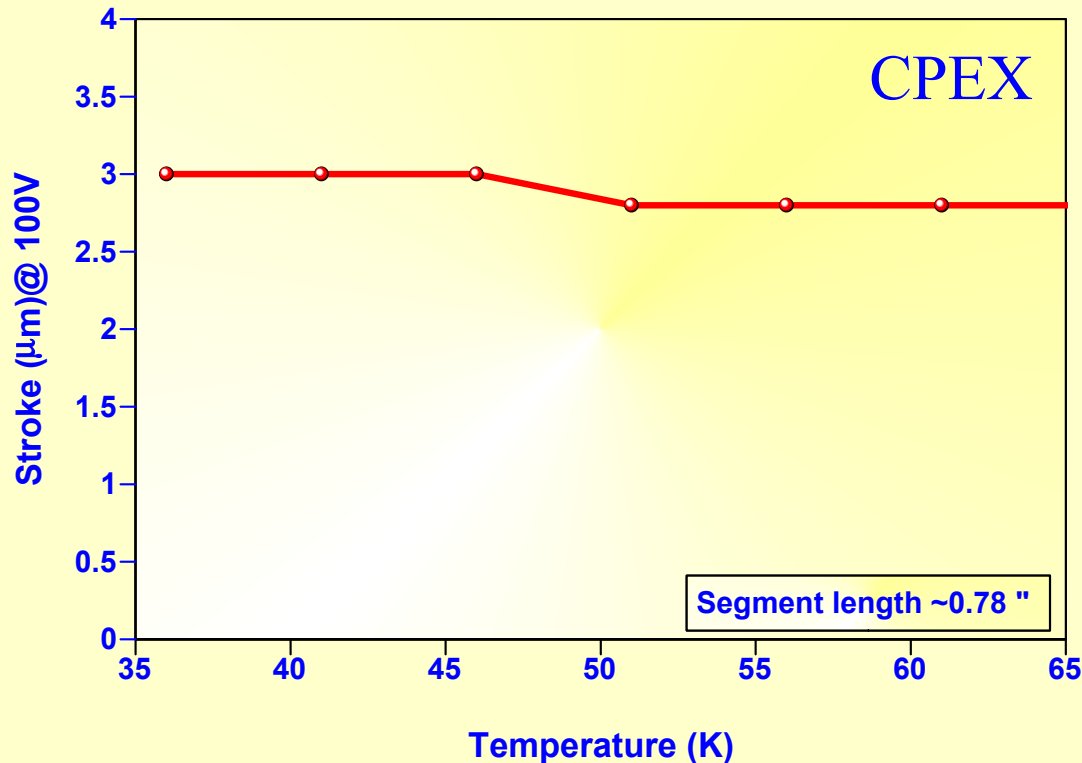
Xinetics Inc.

Precision Motion Under Intelligent Control

Mark A. Ealey, et.al.



## CPEX: Near- Linear Performance 35 to 65 K *$\Phi$ 3 Material for Room & Cryo Temperature Response*



Operates from 25 to >375 K

**Xinetics Inc.**

Precision Motion Under Intelligent Control

Mark A. Ealey, et.al.



# Cryogenic DM Status Summary

## ACCOMPLISHMENTS TO DATE

- ◆ Developed an electrostrictive electroceramic for 35-65K
- ◆ Developed a piezoelectric electroceramic for 35-375K
- ◆ Delivered two 37-ch cryogenic DMs using cut & bond actuators
- ◆ Delivered a 349-ch cryogenic DM using cut & bond actuators
- ◆ Developed cryogenic cofired actuator technology
- ◆ Developed XiMux multiplexed electronics
- ◆ Built a cryogenic testing chamber for actuators and DMs up to 15 inches diameter
- ◆ Successfully cycled the 37-channel DM to 35K
- ◆ Successfully demonstrated DM actuation at 50K
- ◆ Delivered a 349-ch cryogenic DM using cofired discrete actuators
- ◆ Delivered a 349-ch cryogenic DM using cofired modular actuators
- ◆ Delivered a 349-ch XiMux Driver System to operate DMs.

## STILL TO BE DONE

- ◆ Cryogenic testing of 349-ch cofired DM.
- ◆ Demonstrate cryo-null figuring of 349-channel cofired DM.
- ◆ Complete optimizations of 349-ch cryogenic modular mirror (Optimizations stopped in infancy due to program descope, need to bring to maturity)
- ◆ Miniaturize XiMux electronics by transferring to low power hybrid or ASIC (not funded)
- ◆ Space qualification (not funded)



349-ch Cofired Cryogenic DMs  
Modular (left) & Discrete (right)

**Xinetics Inc.**

Precision Motion Under Intelligent Control

Mark A. Ealey, et.al.